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This research project focussed on the enhancement of crrent vehicle simulation capabilities of TARDEC. Problems addressed included development of new numerical algorithms for efficiently simulating mechanical systems with low-amplitude, high-frequency vibrations, and development of numerical methods and models for impacts and collisions.

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EFFECTIVE NUMERICAL METHODS FOR VEHICLE DYNAMICS

FINAL PROGRESS REPORT

LINDA R. PETZOLD

SEPTEMBER 17, 1996

U.S. ARMY RESEARCH OFFICE

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UNIVERSITY OF MINNESOTA

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1 Statement of the problem studied

This research project focussed on the enhancement of current vehicle simulation capabilities of TARDEC. Problems addressed included development of new numerical algorithms for efficiently simulating mechanical systems with low-amplitude, high-frequency vibrations, and development of numerical methods and models for impacts and collisions.

2 Summary of the most important results

High-frequency oscillations in nonlinear ODE/DAE systems are a problem in vehicle simulation because following the oscillations necessitates the use of an extremely small timestep. However, many of the oscillations are not important for the overall numerical solution. We have shown that methods based on local linearization can fail because the local eigenstructure of the problems oscillates at the high frequency. Experiments have demonstrated that certain implicit methods combined with automatic stepsize control can damp out the oscillation safely, in regions where its amplitude is too small to be important. The usual stepsize selection strategies must be modified so that they are correct for the limiting high-index DAE. There is also some theory to support this technique for the equations of motion. However, once the stepsize is increased, problems with Newton iteration convergence again restrict the timestep. These problems are also due to the rapidly changing local eigenstructure. Some formulations of the equations of motion are more advantageous than others in terms of Newton iteration convergence for highly oscillatory systems. A coordinate-split (CS) method has been developed that, together with a modified Newton (CM) iteration is particularly effective. Numerical results for a number of highly oscillatory multibody systems demonstrate that the new method is particularly effective for highly oscillatory systems where the oscillation is small and can be damped. Recently developed theory explains the Newton convergence results. Investigation of the high-frequency oscillation problem was motivated by discussions with Roger Wehage and Jim Overholt (TARDEC).

Modeling impact of bodies or particles during a physical system simulation is problematic and may cause many difficulties in the numerical solution. On the other hand, it can better define the dynamics of some systems, such as in track vehicle simulation. It is well-known that a purely algebraic treatment of the rigid impact problem can lead to incorrect results in some cases. To remedy this, Keller proposed a set of evolution equations which can be used for non-trivial three-dimensional impact problems. For the hypothesis of impact, Stronge proposed a resititution model that overcomes the difficulty of using either Newton's or Poisson's stopping criterion. A rigid impact model between the road-wheel and track has been developed using Keller's evolution equations. The coefficients of friction and restitution are the only input parameters. By adjusting the coefficients, accurate tensional forces applied to the track can be computed using the tangential impulse. Two-body impact evolution equations were generalized for the constrained multi-rigid-body impact model, e.g., rigid impact between the road-arm and road-wheel composite body and the chain of track segments. Compared to the conventional track model, where one has to guess the soil deformation, and then compute the shear and normal forces between the ground and track, this approach yields a more accurate and effective computational scheme to treat the complex track model. This work has been in collaboration with G.P. Mac Sithigh at the Mechanical and Aerospace Engineering and Engineering Mechanics department, University of Missouri-Rolla.

3 Publications and Technical Reports

L. R. Petzold and J. Yen, *An Efficient Newton-Type Iteration for the Numerical Solution of Highly Oscillatory Constrained Multibody Dynamic Systems*, submitted to SIAM J. Sci. Comput.

J. Yen and L. R. Petzold, *Numerical Solution of Nonlinear Oscillatory Multibody Systems*, in Numerical Analysis 1995, Pitman Research Notes in Mathematics Series, Vol. 344, D. F. Griffiths and G. A. Watson Eds., 1996.

J. Yen and L. R. Petzold, *Computational Challenges in the Solution of Nonlinear Highly Oscillatory Multibody Systems*, in Numerical Analysis of Or-

dinary Differential Equations and its Applications, ed. T. Mitsui and Y. Shinohara, World Scientific, 1995.

J. Yen and L. R. Petzold, *Convergence of the Iterative Methods for Coordinate-Splitting Formulation in Multibody Dynamics*, Department of Computer Science, University of Minnesota, 1995.

J. Yen and L. R. Petzold, *On the Numerical Solution of Constrained Multibody Dynamic Systems*, Dept. of Computer Science, University of Minnesota, 1994.

4 List of all participating scientific personnel

The personnel participating in this project were: PI: Linda R. Petzold, Postdoctoral research associate: Jeng Yen, Graduate research assistants: T. Maly (M.S. in Computer Science, 1995), S. Li, S. Raha.

5 Report of inventions

None.